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Clinical experience with the oxygen concentrator

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Abstract

The oxygen concentrator is an accepted means of delivery of long term domiciliary oxygen treatment. Conditions of use, however, need to be carefully defined. Fourteen concentrators were used for one year by patients with hypoxaemic chronic obstructive airways disease, and mechanical reliability, patient compliance with a regimen of 15 hours' use a day, smoking habits, and variation in arterial gas tensions studied.

Though many patients failed to achieve either the desired daily use or the recommended arterial oxygen tension, problems were generally minor and could probably be overcome by careful supervision and planning. Overall the concentrator appeared to be the most economical means of providing oxygen treatment at home and was much preferred by patients who had previously used oxygen cylinders.

Introduction

Patients with chronic obstructive airways disease, hypoxaemia, and oedema benefit from long term domiciliary oxygen treatment. Studies by the Medical Research Council and National Institutes of Health in such patients showed a substantial long term reduction in mortality.^{1,2} To achieve this oxygen was required for at least 15 hours a day at flow rates sufficient to raise the arterial oxygen tension (P_{aO_2}) to 8.0 kPa (60 mm Hg)—usually around 2 l/min. There are three methods of providing long term domiciliary oxygen: cylinders of 1360 l delivered to the patient's home (the most widely used method), liquid oxygen in a domestic tank replenished twice weekly (used only in

Edinburgh in the United Kingdom), and the oxygen concentrator.

The oxygen concentrator is about the size of a small refrigerator and separates nitrogen from air on a "molecular sieve". It will deliver oxygen to the patient at concentrations of 90% and at flow rates up to 4 l/min.³ The capital cost of the concentrator is £1200, which may be considered expensive in relation to the size of the patient population. Nevertheless, the yearly running cost of £150-200 is substantially less than the £4000 for providing cylinders and the £1500 for liquid oxygen.⁴ Thus on cost alone the oxygen concentrator is the preferred means of providing long term domiciliary oxygen treatment. Although the machines are used world wide, they have not been tested under prescribed therapeutic conditions demanding 15 hours of use daily. This study was devised to assess the mechanical reliability of the concentrator, patient compliance, and the therapeutic efficacy of oxygen concentrators over a period of 12 months.

Method

Fourteen concentrators were allocated to patients with cor pulmonale secondary to chronic obstructive airways disease living in the Sheffield area. One machine was held in reserve at the hospital. Of the 15 concentrators, 12 were De Vilbiss DeVO₂ machines and three Rimer Birlec DOM 9 machines. At the beginning of treatment arterial gas analysis was performed to ensure that a P_{aO_2} of at least 8 kPa was maintained at a flow rate of around 2 l/min. Patients were instructed to use the machines for 15 hours a day and those who smoked cigarettes advised to stop in the strongest possible terms. Every three months technical staff visited the patients' homes to read the (hidden) clock, change air filters, perform minor servicing as appropriate, and ensure that the concentration of oxygen delivered by the machine was at least 90%. Servicing was carried out by a trained medical physics technician from our department in order that mechanical reliability could be more accurately measured than through the manufacturers' servicing arrangements. In the event of total failure of a machine, the patient was instructed to telephone our respiratory function laboratory. No back up oxygen cylinder was provided, as any machine requiring withdrawal from service was immediately replaced by the reserve concentrator.

Patients were seen at regular intervals in the outpatient department for clinical assessment. After the concentrators had been in use for 12 months we calculated the hours of use a day, allowances being

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made for absence due to medical or social reasons, which each patient had been asked to note. Blood gas analysis was performed between 8 and 9 am after the patients had been breathing oxygen overnight and again in the late afternoon when they had not taken oxygen for at least two hours. Carboxyhaemoglobin estimations were performed on the same samples. Analysis of costs accrued by the service for visits, maintenance, and investment in spare parts was made for the 12 month period. A questionnaire asking about ease of operation, noise, and general convenience of the concentrator was also returned by each patient.

Results

Mechanical performance was essentially good (table I). No machine totally failed, although seven were temporarily withdrawn. Two serious mechanical faults did, however, emerge. The valve linking the two molecular sieves in one machine failed, resulting in the bypassing of one bed and consequent delivery of an oxygen concentration of under 50%. More important, after 12 months' use three other machines were found to be producing less than 90% oxygen. The manufacturers subsequently discovered that this was due to partial exhaustion of the molecular sieves. These are readily replaced, but the reason for their premature failure is not known.

Table I shows the cost of providing technical services from our department. A service contract offered by the manufacturers is given for comparison, although only two home visits a year were provided. The cost to this hospital for the 12 months amounted to £165.00 per machine, including the refunding of electricity costs; this was £10 more than would have accrued from using service contracts. The capital costs of providing workshop facilities and trained staff to give such a service, however, confirm that for fewer than 10 concentrators the use of hospital servicing would not provide substantial savings.⁴

Table II shows the degree of patient compliance with the recommended usage 15 hours a day and the directive to give up smoking. Only 13 sets of data were available owing to failure of one of the clocks. Patients used the machines for a mean of just over 13 hours a day. Only two patients achieved 15 hours' use or more daily, the minimum necessary for clinical benefit to accrue.⁵ Estimations of carboxyhaemoglobin saturation were performed simultaneously. These data confirmed that 10 patients continued to smoke, although only five admitted to doing so.

Table III gives the results of blood gas analysis on two separate occasions. After 12 months' use of the concentrator the mean P_{aO_2} was 7.4 kPa (55.6 mm Hg) and mean P_{aCO_2} 6.9 kPa (51.9 mm Hg). Only three patients attained a P_{aO_2} of 8 kPa (60 mm Hg) aimed at in the study and achieved by all at the start. The failure of 11 patients to achieve a satisfactory oxygen tension while receiving treatment was clearly unacceptable. Consequently in early 1983, 13 further home visits were made (one patient had died) to determine whether low oxygen concentrations or inadequate delivery rates were responsible (table III). Mean P_{aO_2} was improved on this second occasion after a reminder about flow rate and 10 patients achieved a P_{aO_2} of 8.0 kPa or more. The flow rates set by the patients themselves (ostensibly

TABLE III—Arterial blood gas analysis (arterial P_{aO_2}) oxygen and carbon dioxide (P_{aCO_2}) tensions in kPa)

	Visit 1 (1982; n = 14)				Visit 2 (1983; n = 13)			
	On O ₂ (am)		Off O ₂ (pm)		On O ₂		O ₂ concentration (%)	Actual flow (l/min)
	P_{aO_2}	P_{aCO_2}	P_{aO_2}	P_{aCO_2}	P_{aO_2}	P_{aCO_2}		
Mean	7.4	6.9	5.9	6.3	8.3	7.0	89.5	1.59
Range	5.5-11.5	5.7-8.4	4.4-7.9	5.1-8.6	6.6-11.6	5.8-9.7	78-100	1.0-2.0
Standard deviation	1.70	1.10	0.98	0.87	1.56	1.02	5.24	0.30

Conversion: SI to traditional units— P_{aO_2} , P_{aCO_2} : 1 kPa \approx 7.5 mm Hg.

2 l/min) varied from 1 l to 2 l/min. Two patients had reduced the flow rates because of severe morning headache, and although mean P_{aCO_2} at the second visit was 7.0 kPa (52.6 mm Hg) (compared with 6.3 kPa (47.4 mm Hg) when not breathing oxygen), the range was considerable. Thus while there was some carelessness in adhering to prescribed flow rates, problems with hypercapnia were evident in some patients. Oxygen concentrations delivered by the machines varied from 78% to 100% (mean 89.5%), resulting in three concentrators being returned to the manufacturers as described. Impending failure of molecular sieves is easily detected and readily dealt with but regular checks need to be written into any servicing protocol.

Of the nine patients who had had home oxygen supplied via cylinders before being allocated a concentrator, seven preferred the concentrator for its easier operation and particularly because it did not require deliveries of cylinders with their associated manhandling problems.

Discussion

The aim of this study was to maximise the problems associated with providing a domiciliary oxygen concentrator service. Problems were identified in all categories examined, although most were minor. A regimen of 15 hours of oxygen daily puts considerable strain on both patient and equipment. It was always expected that such intensive treatment would require a code of practice for patient support and maintenance of equipment. This was the first time that the concentrator had been studied under conditions of intensive usage, but the results confirm that the equipment is the most economical means of providing oxygen at home.

Mechanical performance was good for the most part. On only 17 occasions from 56 visits were machines withdrawn from service. We found the De Vilbiss the more reliable machine (table I). The availability of a spare concentrator obviated the need to keep an expensive oxygen cylinder in the patients' homes as a reserve supply. Premature exhaustion of molecular sieves was surprising and the cause is under investigation; it may, however, be related to industrial pollution of the atmosphere in this region. Such failure is easily detected by a falling oxygen concentration of the effluent gas.

The lack of patient compliance with a 15 hours a day regimen and the inadequate P_{aO_2} of some patients need further study. While part of the problem may be attributed to carelessness of the patient in not adhering to the prescribed flow rate, it was clear that hypercapnia and machine problems contributed. During the Medical Research Council trial patients were visited at home every six weeks.¹ In our study for technical reasons visiting was done every three months, the patients being seen in the outpatient department in between. To achieve the vital extra two hours of patient compliance daily probably further patient support will be needed. Patients need to be constantly reminded of the importance of their treatment. A health visitor or respiratory health worker might effectively fulfil this function. When long term domiciliary oxygen treatment was first introduced progressive hypercapnia was feared. These fears were never realised in early studies and the problem was dismissed. With the advent of the oxygen concentrator and more precise

TABLE I—Mechanical performance and servicing costs (1981-2); 14 machines

	De Vilbiss DeVO ₂	Rimer Birlec DOM 9	Total
<i>Mechanical performance</i>			
Machine types	12	3	15
Servicing requiring removal	1	6	7
Faulty components	0	6	6
Molecular sieve exhaustion	3	2	5
<i>Servicing costs</i>			
Cost of yearly service contract (twice yearly visits with filter changes) for 14 machines (£)			1176
Yearly cost of quarterly visits by hospital staff for 14 machines (£)			962

TABLE II—Patient compliance

	No studied	Mean	Range	Standard deviation
No of hours of use daily	13	13.27	9.0-16.5	2.0
Carboxyhaemoglobin saturation (%)	am	4.43	1.7-11.5	2.9
	pm	7.12	2.4-14.2	3.5

attention to inspired flow rates, however, it seems that clinically compromising hypercapnia may develop. In our study several patients reduced the recommended flow rate because of headache and shaking. Despite this, most of the patients who had used cylinders before being allocated a concentrator found the concentrator a more acceptable means of oxygen delivery.

We conclude that the oxygen concentrator is the most economical means of providing domiciliary oxygen and appears to be acceptable to patients as a delivery system. Patients shown to benefit so far are those with cor pulmonale associated with chronic obstructive airways disease. The installations need to be supervised by chest physicians with a special interest in the treatment. After installation the oxygen flow rates should be adjusted in the home environment to achieve a PaO_2 of at least 8 kPa (60 mm Hg). This will be the recommended flow rate given to the patient. Machines need to be checked at minimum intervals of three months. For physicians concerned with only one or two machines it would be far better to arrange servicing through the manufacturer. At each visit the oxygen concentration of the effluent gas should be checked as well as the filters and mechanical components of the machine. The flow rate used by the patient should be compared with the recommended level. All machines should be purchased with a clock inside the mechanism so that the hours of daily use can be calculated. Ideally arterial gas tensions should be measured at each visit. The recent introduction of transcutaneous oxygen electrodes might simplify this process. A 24 hour replacement service for faulty concentrators works adequately and would save the cost

of a spare cylinder. The dangers of smoking need to be constantly emphasised.

Large numbers of concentrators are now being sold. It must be remembered that few machines have been tested under the circumstances described in this study. Thus when the oxygen concentrator is introduced physicians must be careful to determine that the manufacturer is aware of the problems described and that equipment servicing schedules are designed to deal with them.

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SHORT REPORTS

Swimming pool wheezing

Swimming in indoor pools is promoted as an activity in which most people with asthma can participate without experiencing exercise induced wheeze.¹ Within the past few years, because of rapidly increasing energy costs, operators of about 200 public swimming pools have installed sophisticated heat reclamation systems that recirculate pool air and therefore concentrate chlorinous smells.

Chlorine gas is being largely phased out as a disinfectant of pool water for safety reasons, and the effects of other chlorine sources on bather comfort have recently been studied.² I carried out a survey using standard challenge swims in which bathers were asked to swim for 20 minutes sufficiently vigorously that they could just hold a conversation; they were allowed to rest holding the pool side when necessary. Standard temperatures (water 27.8°C and air 28.9°C) were usually maintained in the pools studied. During this study it became clear that some people with asthma (and some subjects with no history of wheezing) suffered attacks of bronchospasm when heat reclamation systems were in operation. Several small outbreaks and some individual cases were reported to me, and I investigated seven subjects. I describe here one typical case of swimming pool wheezing to illustrate the problems that may occur.

Case report

A 57 year old man who was keen on physical exercise, especially jogging, swam regularly in two swimming pools in the same town. Both pools were under the same management, used the same water supply and the same disinfectant, and were maintained to the same standards. One pool had been built recently and used a heat reclamation system that recirculated a high proportion of the air in the pool hall and was controlled automatically. The older pool had a simple air extractor, which was under the control of the pool attendant.

The patient complained of coughing, sometimes severe, for 12 to 24 hours after swimming in the modern pool. He was apparently unaffected by swimming in the old pool. Swimming in the modern pool affected him more severely in winter than in summer. He related his coughing to "chlorine gas" present in the pool air but could not account for the seasonal variation or difference between the old and modern pools. There was no personal history

of asthma exercise induced asthma, or atopy, although his sister had late onset asthma and his 28 year old daughter had had asthma since childhood. Examination showed that he was in excellent health; height was 1.778 m (5' 10") and weight 68.9 kg (10 st 12 lbs). His vital capacity was 4.1 l, and forced expiratory volume in one second (FEV_1) 3.3 l.

Standard challenge swims in the new pool on two occasions reduced the FEV_1 to 2.2 l and 2.5 l respectively; bronchospasm was present on auscultation. Two challenge swims in the old pool reduced the FEV_1 from 3.3 to 3.1 l; 30 minutes' jogging did not affect it. Breathing air at water level in the modern pool for 20 minutes without exercising on two occasions reduced the FEV_1 to 2.5 l and 2.6 l respectively.

Comment

Contrary to a widely held belief the chlorinous smells in swimming pools are caused not by chlorine gas but by nitrogen trichloride (an intense irritant) and, to a lesser extent, monochloramine and chloroform, which are produced when free chlorine (in solution as hypochlorous acid) reacts with organic contaminants introduced into the pool by bathers.³ These contaminants are mainly urea and creatinine, which come from urine and sweat. Provided that organic contaminants are not present irritants are not produced and swimmers experience virtually no eye or respiratory problems.

The mechanism of production of bronchospasm in the patient described was probably similar to that in an outbreak in Manchester, in which an irritant stimulated hyperreactive bronchi.⁴ Chlorine dioxide, which had been used to disinfect the water in Manchester, is no longer recommended because of severe recurring problems.⁵

The patient described here was troubled more when swimming in the winter because the automatically controlled heat reclamation system recirculated a high proportion of air in the winter to conserve heat and, conversely, expelled a high proportion of warm air in the summer because of solar heat gain. Nitrogen trichloride was therefore more concentrated in the winter and his bronchospasm more severe. In the older pool the simple air extraction system controlled by the bath attendant facilitated increased extraction of air when chlorinous smells became stronger.

In the modern pool complaints of respiratory and eye irritation were common from swimmers, spectators, and staff. The baths manager reported that these complaints had stopped almost entirely when a